Nature Conservation 9: 19–43 (2014)
doi: 10.3897/natureconservation.9.8385
http://natureconservation.pensoft.net

CONSERVATION IN PRACTICE

A peer-reviewed open-access journal
Nature Conservation
Launched to accelerate biodiversity conservation

Nature conservation on agricultural land: a case study of the endangered Carnaby's Cockatoo *Calyptorhynchus latirostris* breeding at Koobabbie in the northern wheatbelt of Western Australia

Denis A. Saunders[1], Rick Dawson[2], Alison Doley[3], John Lauri[4], Anna Le Souëf[5], Peter R. Mawson[6], Kristin Warren[5], Nicole White[7]

1 *CSIRO Land and Water, GPO Box 1700, Canberra ACT 2601, Australia* **2** *Department of Parks and Wildlife, Locked Bag 104, Bentley DC, WA 6983, Australia* **3** *Koobabbie, Coorow, WA 6515* **4** *BirdLife Australia, 48 Bournemouth Parade, Trigg WA 6029* **5** *College of Veterinary Medicine, Murdoch University, South Street, Murdoch, WA 6150* **6** *Perth Zoo, 20 Labouchere Road, South Perth, WA 6151, Australia* **7** *Trace and Environmental DNA laboratory, Curtin University, Kent Street, Bentley, WA 6102*

Corresponding author: *Denis A. Saunders* (denis.saunders@csiro.au)

Academic editor: *Klaus Henle* | Received 5 August 2014 | Accepted 21 October 2014 | Published 8 December 2014

http://zoobank.org/660B3593-F8D6-4965-B518-63B2071B1111

Citation: Saunders DA, Dawson R, Doley A, Lauri J, Le Souëf A, Mawson PR, Warren K, White N (2014) Nature conservation on agricultural land: a case study of the endangered Carnaby's Cockatoo *Calyptorhynchus latirostris* breeding at Koobabbie in the northern wheatbelt of Western Australia. Nature Conservation 9: 19–43. doi: 10.3897/natureconservation.9.8385

This paper is dedicated to the late John Doley (1937–2007), whose wise counsel and hard work contributed greatly to the Carnaby's Cockatoo conservation program on Koobabbie.

Abstract

Nature conservation and agricultural production may be considered as conflicting objectives, but for a wheat and sheep property in Western Australia they have been pivotal management objectives for the last 48 years. Koobabbie, a 7,173 ha property, has retained 41.5% of the original native vegetation, and is a designated Important Bird Area by BirdLife Australia, while still being an economically profitable agricultural enterprise. Since 1987 the owners of Koobabbie have kept detailed records of the avifauna of the property, and encouraged staff from government, non-government and academic organisations to conduct research and monitoring of the endangered Carnaby's Cockatoo *Calyptorhynchus latirostris* breeding on their property. In addition, they have instituted control programs for two over-abundant cockatoo species which compete with Carnaby's Cockatoo for nest sites, and for Feral Cats that are predators of

Copyright *Denis A. Saunders et al.* This is an open access article distributed under the terms of the Creative Commons Attribution License (CC BY 4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

nesting female Carnaby's Cockatoo and their offspring. This paper presents the results of research and monitoring from 2003-2013, during which seven artificial nesting hollows were erected, and former active nest hollows that had become derelict were repaired. By 2008, the number of breeding pairs on the property was at least 27, but two mass deaths of breeding females in 2009 and 2012 reduced the number of breeding pairs by 80%. This study illustrates the importance of monitoring conservation on private property, and raises a number of issues in relation to management of endangered species dependent on large hollow-bearing trees on private property.

Keywords

Carnaby's Cockatoo, *Calyptorhynchus latirostris*, hollow nesting, nestling condition, wildlife conservation, habitat restoration, endangered species management, ecological and economic sustainability

Introduction

Changes in land use and habitat conversion pose the greatest threats to biodiversity throughout the world. Agricultural intensification is one of the major threats (McNeely et al. 1995). It has resulted in the reduction in the extent and the fragmentation of remaining native vegetation (Saunders et al. 1991). The loss of woodlands and forests pose particular problems for species dependent on hollows (or cavities) in large trees for breeding or shelter sites (Newton 1994). Throughout southern Australia there have been major losses in extent and connectivity of temperate woodlands, and deterioration in the quality of the remainder (State of the Environment Advisory Council 1996, Gibbons and Lindenmayer 2002, Saunders et al. 2003, 2014a). This has a major impact on those species that are dependent on hollows for breeding and shelter (Goldingay 2009, 2011), both in terms of the loss of existing large hollow-bearing trees, and competition for the remaining hollows.

Throughout the world's agricultural zones, nature conservation and intensive agricultural production may be considered as conflicting objectives, but for one wheat and sheep property called Koobabbie in the Waddy Forest district in the northern wheatbelt of Western Australia (WA) (29°56'S; 116°09'E) they have been joint management objectives for the last 48 years.

Koobabbie was not cleared of native vegetation when taken up by Alison Doley's grandparents in 1906. Since then it has been developed as an economically profitable agricultural enterprise by three generations of the same family. In 1966, Alison and John, her late husband, took over management of Koobabbie. Their management objective was ecological and economic sustainability (Doley 1995, 2003). Native vegetation remains on 41.5% of the property, and a further 2.3% of the property was revegetated with native species. Nature conservation features strongly in their management objectives.

Between May 1987 and the end of 1990, the Doleys took part in CSIRO Division of Wildlife and Rangelands Research's atlas of birds in the WA wheatbelt project (Saunders and Ingram 1995). During this project they kept weekly records of every species of bird that occurred on Koobabbie and, at the completion of the atlas project, continued collecting these data until the present. Over the 25 years to 2011, 131

species of bird were recorded on Koobabbie. Their data demonstrated that the property is an important site for the conservation of the region's avifauna (Saunders and Doley 2013), and half of Australia's cockatoo species occur on the property: Red-tailed Black-Cockatoo (*Calyptorhynchus banksii*), Carnaby's Cockatoo (*C. latirostris*), Galah (*Cacatua roseicapilla*), Western Corella (*C. pastinator*), Little Corella (*C. sanguinea*) and Major Mitchell's Cockatoo (*C. leadbeateri*) [bird nomenclature follows Christidis and Boles (1994) with the exception of Carnaby's Cockatoo which follows WA Government legislation]. Of these, Carnaby's Cockatoo and Major Mitchell's Cockatoo are of conservation importance under Western Australian legislation.

In the early and mid-1980s, concern was raised about the impacts of clearing of native vegetation on the distribution, abundance, and breeding success of Carnaby's Cockatoo (Saunders 1982, 1986, Saunders and Ingram 1987). In 1987, the Doleys were alerted to the plight of Carnaby's Cockatoo. They took particular interest in the bird's presence on Koobabbie, and made notes of the cockatoo's breeding activities. In 1999, Alison Doley was appointed to the Carnaby's Cockatoo Recovery Team which had been set up to develop a recovery plan for the species and oversee recovery actions (Cale 2003). Knowing the importance of generating more knowledge about the species, the Doleys encouraged those involved in recovery actions to study Carnaby's Cockatoo and conduct relevant recovery actions for the species on Koobabbie.

Since then, staff, volunteers and students, variously from Birds Australia (now BirdLife Australia), WA Department of Conservation and Land Management (now Department of Parks and Wildlife), Perth Zoo, and Murdoch University have worked on aspects of the ecology, genetics and health of Carnaby's Cockatoo on Koobabbie, as well as carrying out repairs to tree hollows used by the cockatoos, and installing artificial hollows. In addition, land care groups carried out revegetation projects to aid recovery of the species in the district. Although the various research activities and observations of Carnaby's Cockatoo on Koobabbie were not coordinated and, to some extent, have been *ad hoc*, a considerable amount of valuable information on the species has been gathered.

This paper presents the results of the diverse research and monitoring activities conducted on Carnaby's Cockatoo at Koobabbie. It demonstrates that valuable information can be extracted from data collected by volunteers and others on an *ad hoc* basis. It examines the conservation implications resulting from the work, particularly as the property is a designated Important Bird Area, mainly for Carnaby's Cockatoo, and makes recommendations for future conservation management, particularly on private property.

Methods

Study area

Koobabbie is located in the centre of the Northern Agricultural Catchment Council (NACC) area. It is an important area for the conservation of the avifauna of the

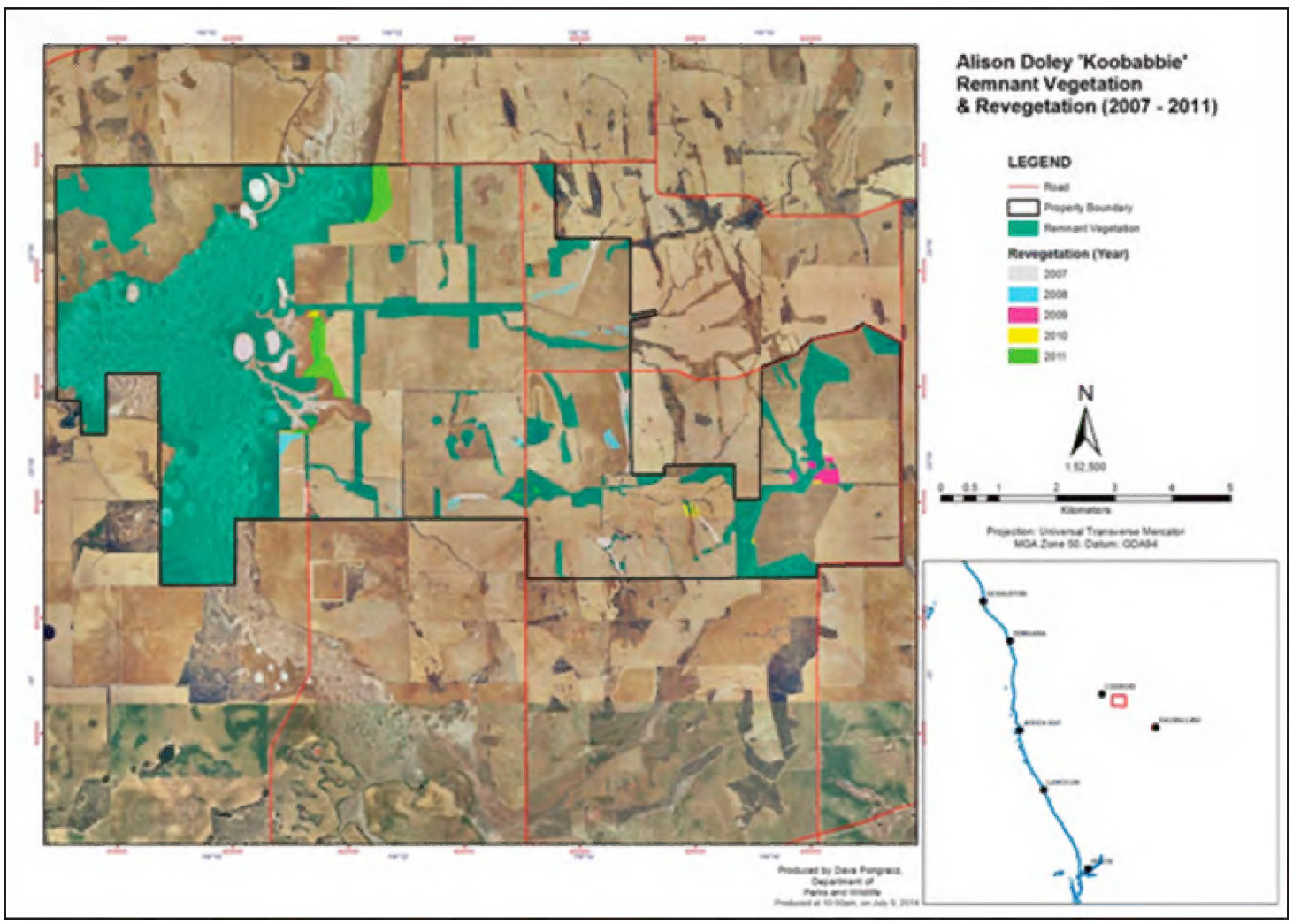

Figure 1. Koobabbie showing property boundary, remnant vegetation, and revegetation 2007–2011).

NACC area (Saunders and Doley 2013). Two hundred and fifty-four hectares of the property are mapped and listed as an important bird area by BirdLife Australia (http://birdlife.org.au/projects/important-bird-areas/iba-maps accessed 9 January 2014) for the support of "up to 32 breeding pairs of the endangered Carnaby's Black-Cockatoo which nest in Salmon Gum on the property", and three other biome-restricted species [Western Corella, Regent Parrot (*Polytelis anthopeplus*) and Blue-breasted Fairy-wren (*Malurus pulcherrimus*)].

Koobabbie has a Mediterranean climate of hot, dry summers and cool, wet winters. The property has a mean annual rainfall of 337 mm (1911–2011 rainfall records from Koobabbie) with 76% of the rainfall occurring between April and September. From 1987 to 2011, total annual rainfall varied from 198.6–560.4 mm. January is the hottest month with a mean daily maximum temperature 36.0 °C and minimum 18.5 °C (data from nearest temperature recording station at Carnamah, 39 km north-west of Koobabbie, Australian Bureau of Meteorology website http://www.bom.gov.au accessed 9th August 2012) and July is the coolest (15.6 °C and 4.6 °C).

The property is 7,173 ha of which 41.5% still retains native vegetation, although 58% of this uncleared land is a major salt lake complex in the property's northeast (Figure 1). Of particular relevance to Carnaby's Cockatoo are the extensive woodland strips that occur throughout the property. These remnants of the original woodlands found in the region are dominated by Salmon Gum (*Eucalyptus salmonophloia*), Gimlet (*E. salubris*) and York Gum (*E. loxophleba*). They provide hollows used for nest

sites by the cockatoos. The remnant vegetation on the deep, yellow, sandy soils mainly found west of Koobabbie includes species of *Banksia*, *Grevillea* and *Hakea* that provide food for the birds. Only 15% of the area within 12 km radius of Koobabbie remains covered with native vegetation (Saunders et al. 2014b).

Between 2007 and 2011, 164.6 ha of revegetation was carried out on Koobabbie (Figure 1). The revegetation is of native species of local provenance. However, it has little value for Carnaby's Cockatoo. The birds nest in the woodland on Koobabbie and forage to the west of the property. Little of the revegetation has been placed where the birds forage and the red clay loam is not suitable for growing species suitable as sources of food. York Gum is the principal species planted in many areas and understorey plants are *Melaleuca* and *Acacia* with no Proteaceae. In slightly saline areas *Atriplex amnicola* has been planted to provide grazing for sheep.

Detailed descriptions of Koobabbie and its management are provided in Doley (1995, 2003) and Saunders and Doley (2013).

Carnaby's Cockatoo

Carnaby's Cockatoo, a large black cockatoo with a distinctive white tail band, is endemic to southwestern Australia. It has been extensively studied (Saunders and Ingram 1998, Saunders et al. 2014b), with one population at Coomallo Creek in the northern wheatbelt of WA being studied in detail from 1969 to the present. In the late 1960s the species was classified as vermin due to its impact on primary production with a bounty on its bill. By the mid-1980s, as a result of destruction and fragmentation of its habitat, it had declined in range and abundance, and became the subject of conservation concern (Saunders 1982, 1990). Currently it is listed as endangered under the Australian *Environment Protection and Biodiversity Conservation Act 1999* and under IUCN Red List category and criteria (IUCN 2014). It is specially protected as "Fauna that is rare or likely to become extinct" in Schedule 1 of the Western Australian *Wildlife Conservation Specially Protected Fauna Notice 2013* under the *Wildlife Conservation Act 1950*. It is the subject of a recovery plan which has recently been revised (Department of Environment and Conservation 2012).

Occurrence data on Carnaby's Cockatoo

From May 1987 to the present, the Doleys recorded every species of bird seen on Koobabbie each week. These data were presence only; for example, one Wedge-tailed Eagle (*Aquila audax*) seen on one occasion during one week was recorded as a tick in the data sheet for that week, as were 100 Western Corella seen every day of the week. In addition, they made notes relating to birds of particular interest. These data and the accompanying notes may be seen on a Supplementary Table to Saunders and Doley (2013) at the journal website http://pcb.murdoch.edu.au. Records of the occurrence

of Carnaby's Cockatoo on the property, together with notes relating to their nesting, behaviour and flock sizes are available from the second half of 1987 to the end of 2013; a period of 28 years.

Carnaby's Cockatoo breeding on Koobabbie

From the breeding season of 2003, staff or volunteers from Birds Australia visited Koobabbie once each year, sometime from late September to early November, and searched for active Carnaby's Cockatoo nests. This was done by looking in each hollow known by the Doleys to be used by Carnaby's Cockatoo, or trees thought to contain a hollow of sufficient size to be suitable for the birds. Any trees with female Carnaby's Cockatoo leaving the hollows or with nestlings or eggs were recorded for subsequent examination. This was carried out by staff from the Department of Conservation and Land Management who recorded the contents of the hollow. If nestlings were large enough to be handled (>3 weeks old), they were measured (length of folded left wing [mm] and body mass [g]), banded (Australian Bird and Bat Banding Scheme bands), and several breast feathers removed for genetic analyses.

The following dimensions were recorded from each hollow used by Carnaby's Cockatoo: height of entrance above ground level (m); diameter of the entrance to the hollow (if circular or the width of the narrowest side, if not circular) (m); depth of the hollow (m); and diameter of the floor of the nest chamber (m). The species of tree providing the hollow was also noted.

Aging of Carnaby's Cockatoo nestlings

Nestlings were aged by comparing the length of their folded left wing (mm) against a reference curve of the length of the folded left wing of known age nestlings from Coomallo Creek, using the method described by Saunders (1986). Saunders (1986) regarded the population at Coomallo Creek as the one in which the nestlings were in the healthiest condition. The accuracy of aging nestlings using this method was ± 4 days applied to nestlings aged around 31 days and ± 6 days applied to nestlings around 64 days. This is a 13% variation at 31 days and 9% at 64 days. This is a reasonable error over a nestling period of more than 70 days. From the nestlings' estimated ages, egg laying dates were extrapolated.

Sexing and kinship of nestlings

Nestlings were sexed based on DNA analysis. DNA-based sex identification targeted the CHD-W and CHD-Z genes located on the sex chromosomes (female, ZW; male, ZZ) using modified primers of Griffiths et al. (1998). Kinship (relatedness) analyses

followed White et al. (2009, 2012) to determine how many and how often individual breeding females nested in hollows on Koobabbie.

Assessment of nestling condition

Saunders (1982) developed a growth curve for Carnaby's Cockatoo based on the relationship between estimated age and expected body mass (g), with standard deviations that ranged from ±20.7% of body mass for nestlings 18 days old, to ±7.4% of body mass for nestlings 68 days old. This reference curve was constructed from measurements of nestlings at Coomallo Creek (1970–1976), 71 km west of Koobabbie. By comparing the observed body mass of nestlings at Koobabbie with their expected body mass relative to their estimated ages based on the measurement of the folded left wing, it was possible to determine which nestlings were in poor condition. Poor condition is defined here as being those nestlings whose body mass was more than one standard deviation below the expected mean body mass for their estimated age (Saunders 1986, Saunders et al. 2014b).

Spacing of active hollows used by Carnaby's Cockatoo

Nearest neighbour analyses, using the distance between the waypoints function on *OziExplorer* GPS Mapping Software, were carried out on all hollow trees used by Carnaby's Cockatoo in the breeding seasons of 2006, 2007 and 2008. These years were chosen because they had the largest number of breeding attempts. In addition, nearest neighbour analyses were carried out on nesting attempts commenced in a series of two-week periods in each of these years. That is, distances (m) to the nearest hollows occupied during weeks 1 and 2 of the breeding season, then weeks 2 and 3, 3 and 4, etc. were calculated. The two-week period was chosen as Saunders (1982) pointed out that females selecting and preparing nest hollows will not tolerate another female prospecting for a nest hollow nearby, but once the female has laid and is incubating, she will tolerate other females nesting as close as hollows in the same tree.

Provision of artificial hollows

On 1 April 2004, seven artificial hollows were erected on Koobabbie. These hollows were constructed of sections of fallen hollow Salmon Gum, with a floor of metal covered with decayed heartwood material from fallen trees, a wooden roof, and an entrance opening to the top and side of the hollow. No measurements were taken of the internal dimensions of artificial hollows, but they were approximately 600–700 mm deep, with an internal diameter of at least 250 mm. They were supported on a

5.8 m length of 100 mm diameter galvanised water pipe. The pipe was supported on a galvanised iron bracket set in concrete with two bolts through the bracket and the pipe, so that by removing one bolt the pipe may be lowered using a front end loader or block and tackle should the hollow need repair. There were several constraints on placement of the artificial hollows; chance of use by Carnabys Cockatoo, vehicle access for erection, and clearance from neighbouring trees. All artificial hollows were erected in woodland known to be frequented by the cockatoos for nesting. Each hollow required access for a tractor with post-hole auger, an eight-tonne truck with 5.8 m of pole and hollow, and a front end loader with a loader bucket. The hollows were placed sufficiently far from neighbouring trees to ensure they would not be damaged should any of those trees fall. The artificial hollows were monitored during the same period natural hollows were monitored.

Control of over-abundant cockatoos and feral cats

Galah and Western Corella compete for hollows with Carnaby's Cockatoo, and in some cases destroy Carnaby's Cockatoo eggs and take over hollows (Saunders 1979, 1982, Alison Doley and Rick Dawson *pers.obs.*). Since November 1989, with appropriate licences, the Doleys have arranged for the destruction of any Galah or Western Corella investigating hollows used by Carnaby's Cockatoo, or in the vicinity of such hollows.

Feral Cats (*Felis catus*) are known to climb trees and prey on cockatoos breeding in hollows, killing nestlings and adults (Saunders 2006). In view of the threats Cats posed to breeding cockatoos, they are controlled on the property opportunistically throughout the year.

Results

Occurrence of Carnaby's Cockatoo on Koobabbie

Carnaby's Cockatoo is a regular breeding visitor to Koobabbie, arriving sometime between the first week in July and the third week in August (median arrival week the last week in July) (Table 1). The birds remain around the property for a period of 22 to 34 weeks (median length of stay 27 weeks) (Table 1), departing sometime between the second week in January and the third week in March (median departure week first week in February) (Table 1). The arrival week of the birds at Koobabbie was significantly correlated ($R^2 = 0.166$; $p = 0.035$) with that year's total Austral autumn rainfall (March to May inclusive) on the coastal plain where they spend the non-breeding season (Figure 2). The wetter the autumn, the earlier the birds arrive at Koobabbie. For example, an increase in annual autumn rainfall of 75 mm advances arrival time by about one week.

Table 1. Week of arrival and departure of Carnaby's Cockatoo at Koobabbie 1987–2013 and the length of time (number of weeks) the birds were on the property. Weeks are numbered from the first week in January with four weeks each month (i.e., 48 recording weeks in the year; for example week 25 is the first week in July).

Week #	25	26	27	28	29	30	31						
# years birds arrived	1	4	7	6	6	2	1						
Week #	2	3	4	5	6	7	8	9	10	11			
# years birds departed	1	2	5	5	6	2	1	2	0	2			
# weeks birds in area	22	23	24	25	26	27	28	29	30	31	32	33	34
# years	1	1	4	3	3	4	3	3	0	2	0	0	1

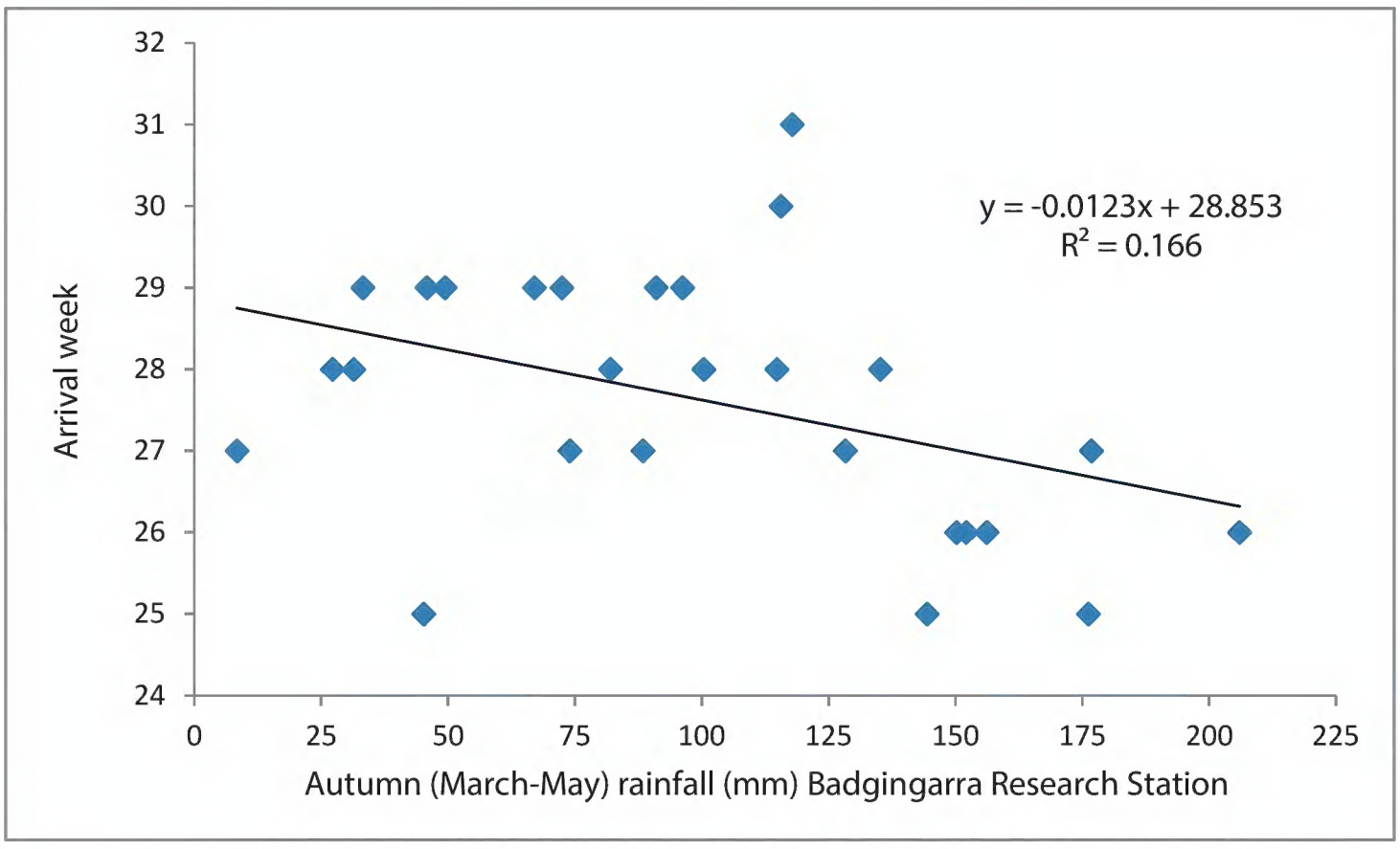

Figure 2. Correlation between week of arrival of Carnaby's Cockatoo at Koobabbie each year (1987–2013), and total autumn rainfall (March-May) each year at Badgingarra Research Station. Rainfall from this station has been used as the birds spend their non-breeding season on the coastal plain from Badgingarra northwards.

Number of breeding attempts 2003–2013

The number of known breeding attempts by Carnaby's Cockatoo at Koobabbie over the 11 years ranged from 18 when monitoring by Birds Australia commenced in 2003, to a maximum of 27 in 2008 (Figure 3). From 2003 to 2013 the number of natural and artificial hollows being monitored increased from 26 to 89. From 2005 to 2013, the monitoring effort for nesting birds was similar. As there were only two monitoring visits each year, these figures represent a minimum number of breeding attempts each year. Accordingly, hollows from which females were flushed on the first visit, that were empty on the second visit, may not have been used, may have been used unsuccessfully, and no evidence remained of the failure, or may have been successful by the time the hollow was checked, but again with no evidence of use.

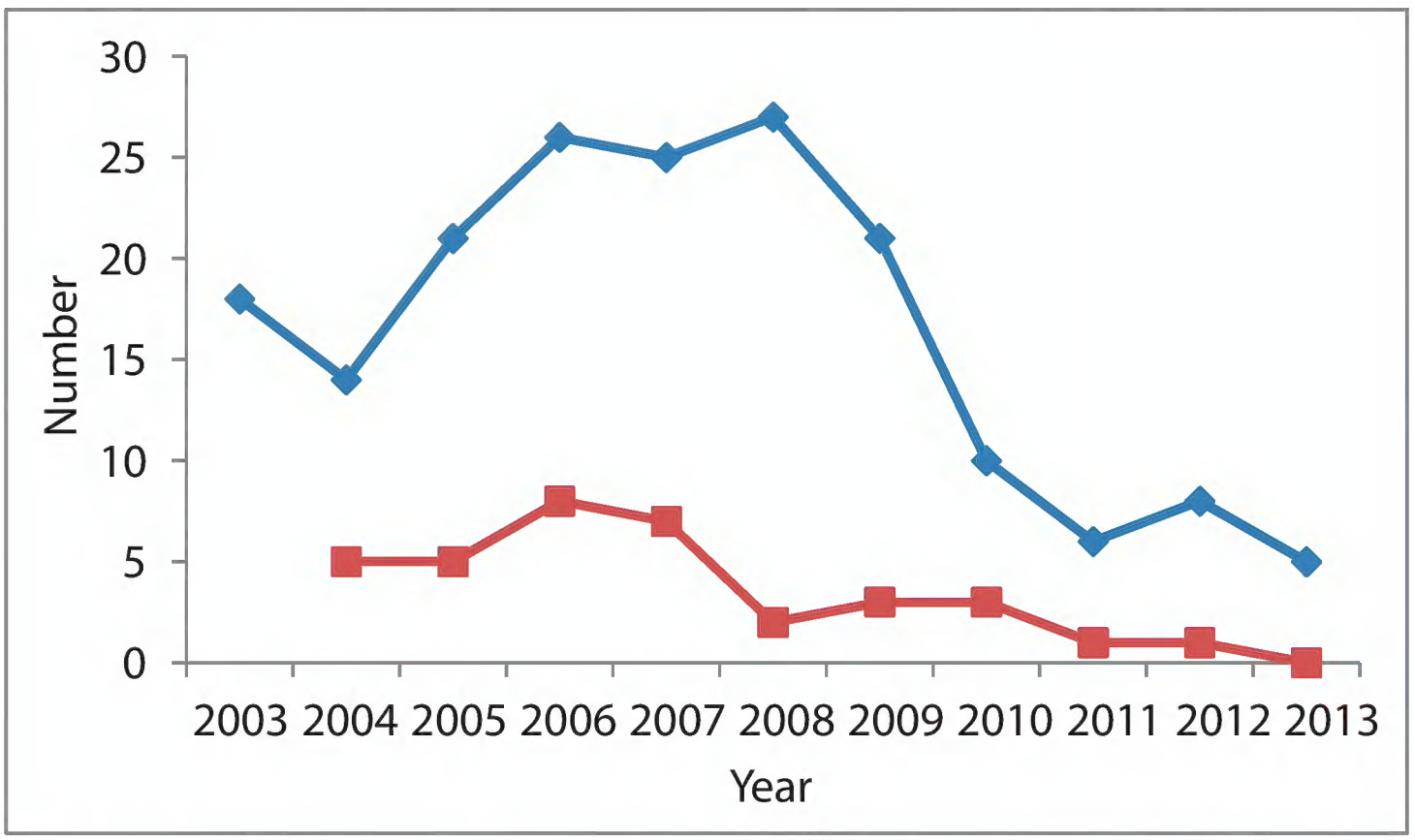

Figure 3. Number of known breeding attempts by Carnaby's Cockatoo at Koobabbie 2003–2013 (diamonds). Known breeding attempts were established by examining the contents of the hollow. Number of female Carnaby's Cockatoo flushed from tree hollows (squares), but the contents were not checked then, or were checked subsequently and no conclusive evidence of a nesting attempt was obtained.

The breeding population in 2009 was less than half that of 2008 due to the death of a number of females, and possibly males. On 30 September 2009, a male Carnaby's Cockatoo was found dragging itself along the ground with its beak. It weighed 434 g, only two-thirds of the average body mass of adult males (Saunders 1974). On 23 October 2009, a mass death of breeding females was recorded with 11 found dead (carcases fly-blown and dried out) in their hollows, and a further five hollows were recorded with abandoned eggs. Four dead females were found on the ground in the nesting area. Dead females were distributed in hollows throughout the woodland areas of Koobabbie, as were the females who successfully bred that season.

There was a similar episode in mid-October 2012, with five females found dead on eggs in their nest hollows. Again, a male with hind limb weakness was found on the ground near the homestead. It was sent for treatment at the Perth Zoo Veterinary Department, but later died. A female found in a moribund state in a nest hollow, was sent to the Perth Zoo Veterinary Department, and later euthanized. Carnaby's Cockatoo feathers on the ground in a belt of woodland indicated an eighth bird had died. These losses again halved the breeding population such that only five breeding attempts were recorded in 2013 (Figure 3); one of these was a second breeding attempt in a hollow where the first attempt failed (Rick Dawson *pers. obs.*).

Necropsies on the two birds found alive, but compromised in 2012, showed no signs of infectious disease or other significant pathological abnormalities, except for the female which had evidence of severe dehydration. Testing was negative for several infectious pathogens including Newcastle disease virus, avian influenza virus, beak

Table 2. Number of first eggs laid by week at Koobabbie 2003–2013. These data relate to the first egg laid in each clutch (clutches of two eggs are most common). No data are available for 2004.

Week	Dates	2003	2005	2006	2007	2008	2009	2010	2011	2012	2013	Total
31	Jul 31–Aug 6					1						1
32	Aug 7–13											
33	Aug 14–20					2		1				3
34	Aug 21–27				2	1		1				4
35	Aug 28–Sep 3	2		3	1	4	1	1	1			13
36	Sep 4–10	1	2	4	1	1			2		1	12
37	Sep 11–17	3	2	2	1	4		2	1	1		16
38	Sep 18–24	2		2	2	3						9
39	Sep 25–Oct 1		1	2	4	1		1				9
40	Oct 2–8				3				1			4
41	Oct 9–15		2	1								3
42	Oct 16–22						1					1
43	Oct 23–29						2					2
44	Oct 30–Nov 5											
45	Nov 6–12						1					1
	Total	8	7	14	14	17	5	6	5	1	1	78

and feather disease virus, avian polyomavirus, *Chlamydia psittaci* and avian adenovirus. Screening was negative for 72 toxins including pyrethrins, organophosphates and organochlorines, and testing for seven heavy metals did not reveal any significant findings. It is highly unlikely that food shortage was the cause of the deaths, as one of the males found alive was in good body condition, and some of the nestlings measured that were in unaffected hollows were within the healthy body mass range.

Timing of egg-laying on Koobabbie

During the period 2003–2013, the earliest that egg-laying commenced was Week 31 (Jul 31–Aug 6) in 2008, and the latest Week 45 (Nov 6–12) in 2009 (Table 2). Over all years, 52.6% of eggs were laid during Weeks 35 to 37 (Aug 28–Sep 17). During the breeding seasons of 2006, 2007 and 2008 when most breeding attempts were recorded, egg-laying took place over a 7-9 week period. In the two years after the 2009 mass deaths, egg-laying also took place over a period of seven weeks (2010) and six weeks (2011).

Numbers of Carnaby's Cockatoo seen on Koobabbie

Maximum flock sizes recorded on the property were: 91 (November 1994); 40 (December 1998); 40–60 (December 1999); 58 (October 2001); 98 (November 2004); 46 (December 2007); 26 (September 2009); 18 (September 2010); 23 (November 2011); 18 (August 2012); and 11 or 12 (September 2013).

Feeding observations

Carnaby's Cockatoo were recorded feeding on Wild Radish (*Raphanus raphanistrum*) (an agricultural weed), Wild Geranium or Corkscrew (*Erodium moschatum*) (an agricultural weed), *Banksia prionotes*, *B. attenuata* and *Hakea preissii* on three occasions, and in 2007 on Canola (*Brassica* spp.), an agricultural crop which was first grown in the area in 1998. DNA analyses were used to examine the intestinal content of one of the paralysed birds brought from the field in 2012. The intestines contained plant families Asteraceae, Myrtaceae, Lauraceae, Rutaceae and a clade within asterids known as lamiids.

Sex and kinship of nestlings

DNA-based sex identification was carried out on 75 nestlings sampled from 2003–2010. Of these, 35 were identified as female and 40 as male (Table 3). There was no significant departure from a 1:1 sex ratio (analysis fitting a generalised linear model), which was also the case at Coomallo Creek (Saunders et al. 2013).

From the kinship analyses, fifteen breeding pairs were identified to have visited Koobabbie, at least twice, accounting for 48% of the offspring sample. Thirteen of these pairs were not recorded as breeding in consecutive years. Six pairs used the same tree at least twice.

Condition of nestlings

Seventy-eight nestlings were measured and weighed at Koobabbie between 2003 and 2013 (Table 4). Of these, 13 (16.7%) were more than one standard deviation below the benchmark and deemed to be in poor condition. In 2009, the first year of the

Table 3. Sex of nestlings at Koobabbie (2002–2010) as determined by DNA analysis.

Year	Females	Males	Total
2002	3	2	5
2003	5	4	9
2004	1	1	2
2005	2	4	6
2006	5	6	11
2007	4	13	17
2008	12	8	20
2009	1	0	1
2010	2	2	4
Total	35	40	75

Table 4. Number of nestlings measured at Koobabbie and the number of nestlings whose body mass was one standard deviation below the benchmark body mass (see text for details). The percentages are the proportion of the total nestlings measured that were more than one standard deviation (SD) below benchmark, and deemed to be in poor condition.

Year	# nestlings	# below -1 SD	% below 1 SD
2003	8	3	37.5%
2005	7	0	0%
2006	14	1	7.1%
2007	14	3	21.4%
2008	17	2	11.7%
2009	5	3	60.0%
2010	6	1	16.7%
2011	5	0	0%
2012	1	0	0%
2013	1	0	0%
Total	78	13	16.7%

mass deaths, 60.0% of nestlings were more than one standard deviation below benchmark body mass.

Comparisons were made between data from Koobabbie and data from 963 nestlings at Coomallo Creek (1970–2013) and 73 from Manmanning (1969–1976). Of the Coomallo Creek nestlings, 110 (11.4%; annual range 0–28.6%) were more than one standard deviation below the benchmark body mass, and at Manmanning 46 (63.0%; 14.3–100%) of nestlings were more than one standard deviation below benchmark body mass.

There was a significant negative linear correlation ($R^2 = 0.110$; $p = 0.004$) between time after the commencement of egg-laying for the season and the percentage nestling body mass deviated from the benchmark (Figure 4). The later eggs are laid in the breeding season, the greater the chances the resulting nestlings were in poor condition.

Dimensions of hollows used by Carnaby's Cockatoo on Koobabbie

Carnaby's Cockatoo nested in hollows in 51 trees on Koobabbie, the dimensions of which are given in Table 5. Forty-nine were in Salmon Gum, and one each in Gimlet and York Gum. The mean depth was 1.32 m, which was similar to the depths of hollows in Salmon Gum used by Carnaby's Cockatoo at Manmanning (Saunders 1979). The mean height of hollow entrances was 5.29 m, which was lower than the 7.38 m at Manmanning. However, the range of 2.2–8.7 m indicates that height of entrance is not of major importance; the size of the hollow in the tree is critical (Saunders et al. 2014a).

Of these hollows, 27 (52.9%) needed some form of repair, and three of the hollow-bearing trees (5.9%) had fallen over by the breeding season of 2013.

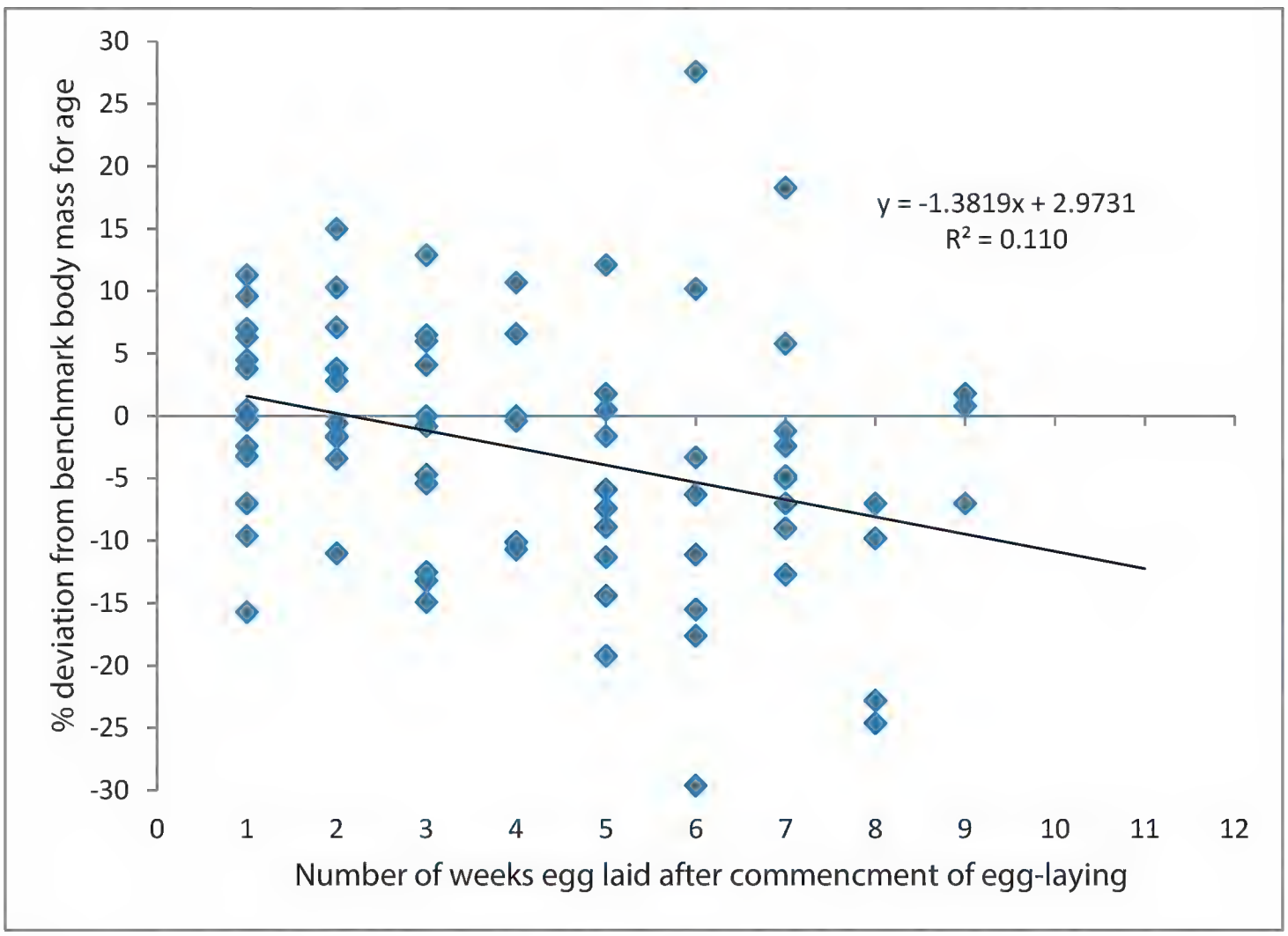

Figure 4. Significant correlation between the percentage of nestlings at Koobabbie whose body mass deviates from the benchmark body mass, and the time at which the egg from which they hatched was laid after the commencement of egg-laying for the season. Egg-laying commenced at Week 1.

Table 5. Dimensions (m) of hollows used by Carnaby's Cockatoo on Koobabbie 2003–2013.

	Height (m)	Depth (m)	Entry Diameter (m)	Floor Diameter (m)
Number	51	49	49	49
Mean	5.29	1.32	0.26	0.33
Median	5.30	1.10	0.25	0.30
St Dev	1.52	0.74	0.08	0.13
Range	2.2–8.7	0.30–3.70	0.10–0.45	0.15–0.70

Spacing of active hollows used by Carnaby's Cockatoo on Koobabbie

Between 2006 and 2008, the average distance between all hollow trees known to be used by Carnaby's Cockatoo at Koobabbie varied from 130 to 180 m (Table 6). However, the average distance between hollow trees in which birds commenced laying at similar times of the breeding season was greater at 600–1050 m. The birds at Koobabbie behave in a similar manner to those at Coomallo Creek, where, over the period 1974–1976, the average distance between the nearest neighbours of all hollows used was 170 ± 10 m, and the average distance between neighbouring hollows laid in a particular week or the previous week was 800 ± 50 m.

Table 6. Average distance (km) to nearest neighbour of all hollow trees used by Carnaby's Cockatoo at Koobabbie during 2006, 2007 and 2008. Also shown is the average distance between nearest neighbours of active hollows started in two-week periods in the same years (see text for details).

	2006	2007	2008	2006–08
Average distance (km) between nearest neighbours of all active hollows	0.18 ± 0.29	0.13 ± 0.16	0.15 ± 0.26	0.13 ± 0.24
Range	0.03–1.23	0.03–0.79	0.03–1.13	0.03–1.2
Average distance (km) between nearest neighbour laid in a particular week or the previous week	1.05 ± 1.02	1.04 ± 1.24	0.60 ± 0.76	0.86 ± 0.99
Range	0.15–3.04	0.13–3.08	0.15–3.10	0.13–3.10

Table 7. Use of the seven artificial hollows installed on Koobabbie before the breeding season of 2004. CC = Carnaby's Cockatoo: E = egg; F = female; N = nestling; RTBC = Red-tailed Black-Cockatoo; and dead refers to the fact that a dead Carnaby's Cockatoo female was found in the hollow.

Nest No	1.10.04	14.10.05	4.10.06	10.10.07	6.11.08	24.10.09	29.09.10	3.10.11	15.10.12	5.11.13	Total
KART 1	F CC	F CC	F CC			F CC					4
KART 2	F CC		F CC 2E		2 CC E		F CC 1E	F CC 1E	Dead CC F 2E		6
KART 3		Galah	Galah		Galah	Galah	Barn Owl				0
KART 4	F CC	F CC 1N	F CC 1N1E	F CC 1N	1 CC N	Dead CC F 1E	1 CC N	F CC 2E			8
KART 5	F CC	F CC 1N1E	F CC 1E	F CC 1N	Galah	1 CC N	RTBC				5
KART 6		Barn Owl	Galah	F CC 1N	Galah						1
KART 7	F CC		F CC 2E	F CC 1N	1 CC N	Dead F CC	F CC		F CC	F CC 1E	8
Total CC	5	3	5	4	3	4	3	2	2	1	

Artificial hollows: costs and use

In 2004, the installation costs of each of the seven artificial hollows were $AUD225 for materials and $AUD330 for labour.

Six were used by Carnaby's Cockatoo at least once over the period 2004 to 2013 (Table 7); 45.7% of the 70 hollow-years they were available. Ten-percent were used by Galah, 2.9% by Barn Owl and 1.4% by Red-tailed Black Cockatoo during the hollow-years available. Artificial Hollow 3 was not used by Carnaby's Cockatoo as the floor of the hollow was too small (Rick Dawson *pers. obs.*). As no follow up visits were made at the end of each breeding season, no data are available on breeding success of birds nesting in artificial hollows.

Movements of Carnaby's Cockatoo from Koobabbie

Eighty Carnaby's Cockatoo nestlings were banded on Koobabbie between 2003 and 2013. It is not known how many of these fledged, or how many returned to breed.

Two fledglings banded at Koobabbie were recorded outside their natal area. One young male was photographed in the Coomallo Creek breeding area on 12 November 2010 (Saunders et al. 2011a). This immature male appeared to be in the company of a female, in a flock that included adults and other immature birds, 71 km west-south-west of its natal area. The second was a female photographed on 12 September 2012, in a flock of up to 400 birds on native vegetation in Beekeepers Nature Reserve, 108 km west of its natal area.

Control of over-abundant cockatoos and feral cats

Of the six cockatoo species occurring on Koobabbie, Galah were the most common; then in decreasing order, Western Corella, Red-tailed Black-Cockatoo, Carnaby's Cockatoo, Major Mitchell's Cockatoo and Little Corella (Alison Doley *pers.obs.*). Galah, Western Corella, Red-tailed Black-Cockatoo and Major Mitchell's Cockatoo were resident on Koobabbie, and Little Corella a vagrant (Saunders and Doley 2013). Galah, Little Corella and Red-tailed Black-Cockatoo were not present in the district prior to clearing of native vegetation for agriculture. These are birds of the arid zone that have extended their range into southwestern Australia as a result of development of agriculture with the provision of grains, agricultural weeds and water for live-stock (Saunders et al. 1985, Saunders and Ingram 1995). Western Corella has increased in numbers on Koobabbie with the development of agriculture (Alison Doley *pers. obs.*), and is present in the district in the thousands.

During September 1995, the Doleys recorded incidents in which Western Corella usurped Carnaby's Cockatoo at five nest hollows known to be used by the latter. In one hollow three Western Corella eggs were removed from the hollow and Carnaby's Cockatoo reclaimed the hollow, and laid two eggs. Subsequently a Western Corella was seen investigating the hollow, and the Doleys found both black cockatoo eggs had holes in the side consistent with them being pecked open. Between 8 February 1997 and 22 March 2014, 11,741 Galah and 4,591 Western Corella were shot on Koobabbie in the vicinity of known black cockatoo nesting hollows.

In October 2007, a female Carnaby's Cockatoo was sitting on two eggs in a hollow in a dead Salmon Gum; this nesting attempt failed as the female was killed by a Cat. Thirty-eight Cats were shot on the property.

Other threats to Carnaby's cockatoo nestlings

During the 2008 breeding season, Alison Doley found Carnaby's Cockatoo nestlings in three hollows were being adversely affected by small black ants (species unknown). This constituted 11% of the hollows known to be used by Carnaby's Cockatoo that season. Previous observations suggested that ants only invaded nest hollows in which there was a dead nestling. In Hollow 24 on 4 December 2008, the nestling was covered

in ants and showing signs of distress. The cloaca and surrounding skin were reddened and scabby. The base of the tree in which the hollow was located was sprayed with chlorpyrifos. The ants were controlled, and by 15 December the nestling had recovered. It fledged on 15 January 2009. One other nestling was found affected by ants. The surrounds of the nest hollow were sprayed, and the nestling fledged on 19 February 2009. No other cases of attack by ants on nestlings were recorded.

Discussion

Carnaby's Cockatoo breeding on Koobabbie

Carnaby's Cockatoo has been a regular breeding visitor to Koobabbie for as long as Alison Doley can remember. Saunders et al. (2013) showed a significant correlation between the commencement of egg-laying and autumn rainfall for birds from Coomallo Creek and Manmanning in which the higher the autumn rainfall, the earlier egg-laying commenced. As data on dates of egg-laying at Koobabbie are limited, week of arrival has been used as an indicator of commencement of breeding. Over the period 1987 to 2012, at Koobabbie Carnaby's Cockatoo conformed to this association with autumn rainfall.

It is difficult to establish a link between the numbers of Galah and Western Corella removed from the local populations, and the steady increase in nesting attempts by Carnaby's Cockatoo. This is in part due to the fact that new nest hollows were still being located after 2005. Anecdotal evidence indicates that the program has been beneficial. For example, in the breeding season of 2007, a Carnaby's Cockatoo commenced breeding in Artificial Hollow 7, but was usurped by a pair of Western Corella. The female Western Corella was shot. The next evening a female Carnaby's Cockatoo was inspecting the hollow; subsequently the hollow was used, with a nestling later banded. Given that the numbers of Major Mitchell's Cockatoo and Red-tailed Black-Cockatoo breeding at Koobabbie also increased during the same period (Alison Doley *pers. obs.*), it seems reasonable to conclude that controlling Galah and Western Corella improved the value of the site for the other three cockatoo species by limiting competition for hollows.

One salient point when considering competition for hollows is that unlike the other cockatoos, which only frequent the nest hollow during the breeding season, Galah guard their breeding hollow throughout the year (Rowley 1990). Galah also have an impact on availability of nest hollows through their destructive habit of "stropping" or chewing the bark away from the trunk of the tree below the nest hollow, in some cases "ring-barking" the tree. This can result in the premature death of the tree (Rowley 1990, Saunders and Ingram 1995: Plate 2).

The six largest artificial hollows were used by Carnaby's Cockatoo during more than half of the hollow-years they were available. Natural hollows formerly used by the cockatoos that were repaired were used soon after being repaired. The rapidity

with which the artificial and repaired hollows were taken up and used indicates that the provision of artificial hollows and repairs of natural hollows are useful strategies for bolstering the stock of nesting hollows.

Condition of nestlings at Koobabbie

Of 60 breeding attempts where nestlings could be measured from 2003 to 2008 (inclusive), 15.0% resulted in nestlings whose body mass were more than one standard deviation below the benchmark established from nestlings at Coomallo Creek. This is similar to the incidence of Coomallo Creek nestlings being in poor condition (11.4%), and much less than the 63.0% recorded at Manmanning. These results indicate that the Koobabbie population was producing healthy nestlings, and was not subject to the same food shortages that led to the extirpation of the population at Manmanning, and a number of other areas throughout the eastern part of the range of the species (Saunders 1986, 1990). However, nestlings raised later in the breeding season are more likely to be in poor condition. This may indicate that food is limited for the population towards the end of the breeding season. It also suggests that, if changes in autumn and winter rainfall patterns continue to occur as predicted (CSIRO 2007, Hennessey et al. 2008), a greater proportion of breeding attempts will occur later in the year, resulting in more low body-mass chicks.

Movements of birds from Koobabbie

The movement records of two fledglings from Koobabbie indicate that the population moves to the coast at the end of the breeding season, and congregates with birds from other breeding populations in the northern wheatbelt (White et al. 2014). One was a four-year-old female, part of a flock of up to 400 birds in the northern sand heaths, west of Eneabba. This is an area where Saunders (1980: Figure 1) reported the Coomallo Creek breeding population and their offspring spend part of the non-breeding season. The other fledgling was a two-year-old male seen in the Coomallo Creek study area. This congregation into groups with other populations provides opportunities for pairs to form in which fledglings from Koobabbie may be mated with fledglings from elsewhere, thus avoiding inbreeding (White et al. 2014). With information on only two fledglings, no light is shed on which sex of fledgling is the one that maintains fidelity to their natal area.

What caused the mass deaths of breeding birds in 2009 and 2012?

Plausible causes of the 2009 deaths include toxicity, infectious disease, or an adverse weather event. Saunders et al. (2011b) ruled out adverse weather as a likely cause because the population at Coomallo Creek was exposed to the same climatic conditions

as the Koobabbie birds and suffered no such mass deaths. Agricultural practices relating to treatment of Canola to prevent insect damage was suggested as a cause. There were no reports of deaths of other species of parrot in the area [including Western and Little Corella, Galah, Major Mitchell's Cockatoo, Red-tailed Black-Cockatoo, Cockatiel (*Nymphicus hollandicus*) and Australian Ringneck (*Barnardius zonarius*)], several of which feed on Canola (Jackson 2009). This may indicate differences in exposure to risk factors due to differing diets, foraging habits or other behaviours.

The reason for the deaths occurring at Koobabbie and not at other similar breeding sites, such as Coomallo Creek, remains unknown, as similar food sources and agricultural practices are present in each area. However, there could be differences in relation to specific methods of agricultural practice, or environmental factors at Koobabbie or adjacent farms that increase the chances of exposure for the birds. What is important is that these data were recorded and shared for future reference (Cox-Witton et al. 2014).

Conservation implications

Koobabbie is the only Western Australian IBA on a private property on which long-term research is encouraged by the owners. This research is important for several reasons. The first relates to Alison and John Doley's approach to conservation. For over 25 years they have kept records of the avifauna of the property, and made the data freely available for others to use (Saunders and Doley 2013). They have conducted fauna and flora surveys of the property, and designated areas of the property for the conservation of the biota, particularly endangered species of plants and animals (Doley 2003). The second is that the Doleys have shown that encouraging and engaging with collaborators from government and non-government conservation agencies, together with those from tertiary institutions, as well as private citizens in the study of Carnaby's Cockatoo over a ten-year period has yielded important results that have application for conservation management, particularly on private property.

Until 2009, the population of Carnaby's Cockatoo on Koobabbie was regarded as one of the most important in the northern wheatbelt. There were at least 27 pairs breeding on the property, and active research and management was carried out. As a result, Koobabbie was known colloquially as "Cockatoo Club Med." However, without this long-term study involving many individuals and organisations, the impact of the 2009 and 2012 mass deaths may have gone unreported. These catastrophic events reduced the breeding population by approximately 80%, and illustrate the impact of stochastic events. The danger is that with such small numbers now breeding on Koobabbie, other factors may come into play and lead to the extirpation of Carnaby's Cockatoo on the property, as has happened in other areas of the range of the species (Saunders 1990).

Knowing that large hollow-bearing trees are being lost on Koobabbie, and replacement stock takes a century or more to provide a hollow for Carnaby's Cockatoo (Mawson and Long 1994), artificial hollows were erected and maintained, and derelict

hollows formerly used by Carnaby's Cockatoo repaired. Both strategies were successful in increasing availability of hollows and were used. These are essential management actions, and should be continued as long as required. However, unless there is a major planting of Salmon Gum to replace the losses of existing trees over the long-term, the woodland will continue to degrade and there will be few large hollow-bearing trees in future (Saunders et al. 2003, 2014a). This illustrates the need to plan for the long-term future, as any revegetation now will only result in useable hollows well into the next century. In undertaking revegetation it is important to consider the potential impacts of climate change. Under changed climatic conditions it may be necessary to revegetate with Salmon Gum from the more arid parts of their distribution, as they are likely to contain arid-adapted genes (Steane et al. 2014), and may be more likely to survive than plants of local provenance (Breed et al. 2013).

As a result of changes in land use in the southwest of WA, conditions have favoured some species, which have increased in range and/or abundance, including Galah and Western Corella (Saunders et al. 1985, Saunders and Ingram 1995, Barrett et al. 2003). Galah and Little Corella have colonised Kangaroo Island, where they compete with Glossy Black-Cockatoo (*Calyptorhynchus lathami*) for nest hollows (Garnett et al. 1999). Garnett et al. (1999) noted that "management to check the growth of both Galah and Little Corella populations is therefore desirable in Glossy Black Cockatoo breeding areas." Between 1998 and 2004, 486 Little Corella were shot (Mooney and Pedler 2005); a rate of 81 birds/year. They regarded this culling as successful because the Little Corella population increased in some areas, and no nestling Glossy Black-Cockatoo deaths were recorded. However, Harris et al. (2012) conducted a population viability analysis of the Glossy Black-Cockatoo (GBC) population on Kangaroo Island, and noted that the "reduction in corella management indicates this culling was almost negligible because of the resilient GBC population." They ran their model on the basis of two Glossy Black-Cockatoos being lost each year to Little Corella, and recommended that culling could be stopped in some areas to conserve management resources. No information was provided on Galah control, if it took place. At Koobabbie, the rate of culling of Galah and Western Corella was 1256 birds/year; a rate 15.5 times that of the rate on Kangaroo Island, indicating a much higher density of nest competitors. We believe that culling is a management action that should be carried out in areas where there is competition for tree hollows between over-abundant cockatoos and endangered species.

It is ironic that Koobabbie has been also designated as an IBA for Western Corella, when it has been subject to control on the property. Western Corella is common through much of the northern wheatbelt with flocks of up to 3,000 seen at Dalwallinu (60 km south-east of Koobabbie), Dongara (143 km north-west), Geraldton (197 km north-west), and Morawa (80 km north) (http://www.dec.wa.gov.au/pdf/plants_animals/living_with_wildlife/1905_butlers_corella.pdf accessed 21 April 2014). Alison Doley is aware that some management for agricultural production favours Western Corella and Galah. Unlike properties surrounding Koobabbie, Koobabbie continues to maintain sheep with 2,400 breeding ewes. For many years, during the

Austral autumn, sheep were fed oats which were spread along the ground in a trail. A few years ago, lupins were grown in the area and added to the trail-feed. Sheep prefer lupins to oats, and consumed lupins first, leaving most of the oats to Western Corella and Galah, which do not feed on lupins. About four years ago, the Doleys ceased supplying oats in the trail-feed. In 2013, 12 lick-feeders were purchased, and in future sheep will be fed oats and lupins from these, reducing the quantity of oats available to cockatoos. Although oats are grown on the property, sheep eat much of the grain left in the stubble after harvest. However, as neighbouring properties do not stock sheep, Western Corella and Galah have wheat available in stubble paddocks in autumn.

Saunders et al. (2014b) suggested that Carnaby's Cockatoo's adaptation of Canola as a food source may have been beneficial to some breeding populations throughout its range. However, the mass deaths at Koobabbie in 2009 and 2012 indicate that further investigation is warranted to determine if there are any agricultural chemicals which may be adversely affecting populations dependent on Canola. Further, there is a lack of understanding about the nutritional benefit of Canola for Carnaby's Cockatoo, as well as the amount of native food sources in addition to introduced plant species, that are required to provide balanced nutrition for breeding birds.

If Canola as a feed source is beneficial to Carnaby's Cockatoo, it should not be used to justify the continued clearing of native proteaceous vegetation. This can now occur under the WA native vegetation clearing regulations, which allow isolated trees and up to 5 ha/year to be cleared without the need for a licence to clear (Environmental Protection Authority 2004). The cumulative impact of the current level of clearing on farms, as well as on road and railway reserves during maintenance activities, continues to reduce the availability of native food, and increases the dependence on agricultural crops such as Canola and other exotic vegetation such as Pines (*Pinus* spp.). Any potential for an increased level of clearing would only exacerbate matters.

At present there is no quantitative estimate of the extent of private property providing breeding and feeding habitat for the species. It is also important that the extent of suitable habitat is established, and incentives developed to encourage more farmers to emulate the example of the Doleys in making nature conservation an objective of their management, and monitoring the outcomes of that management.

Acknowledgements

We acknowledge the following for assistance: Tom Kemp and Bob Veletta who assisted with the monitoring of breeding Carnaby's Cockatoo and repairs of derelict nest hollows from 2003–2013; John Koch for monitoring in 2013; Neil Johns and members of the Sporting Shooters Association of Australia – Western Australia (Inc) who have controlled over-abundant Western Corella and Galah on Koobabbie under licences TF 006233, TF006010, TF005833, TF005677, TF005017, TF004366, TF003762, TF003258, TF002812, TF002680, TF002813 and TF002681 to take

fauna for educational or public purposes; Wally Kerkoff who made the artificial hollows; staff at Perth Zoo for fieldwork and some processing of tissue samples; Dejan Stojanovic, Conservation Officer for the Birds Australia Carnaby's Black Cockatoo Recovery Project for monitoring; and Dave Pongracz of WA Department of Parks and Wildlife for preparing Figure 1. Men of the Trees and WWF-Australia provided funds for construction of the artificial hollows. Field work was conducted under Western Australian Department of Environment and Conservation scientific purposes licences SC000357, SC000920, SC001230, Australian Bird and Bat Banding Authority 1862 and Animal Ethics Committee approvals DEC AEC 11/2005, 32/2008 and 30/2011 held by Peter Mawson. Earlier versions of the manuscript were critically reviewed by Dr Ken Atkins, Dr Stephen Davies, Dr Klaus Henle, Dr Martine Maron and Professor Harry Recher. To all of these individuals and organisations we are grateful.

References

Barrett G, Silcocks A, Barry S et al. (2003) The New Atlas of Australian Birds. Royal Australasian Ornithologists Union, Melbourne, 1–824.

Breed MF, Stead MG, Ottewell KM et al. (2013) Which provenance and where? Seed sourcing strategies for revegetation in a changing environment. Conservation Genetics 14: 1–10. doi: 10.1007/s10592-012-0425-z

Cale B (2003) Carnaby's Black-Cockatoo (*Calyptorhynchus latirostris*) Recovery Plan 2002–2012. Western Australian Department of Conservation and Land Management, Wannaroo, Western Australia, 1–29.

Christidis L, Boles WE (1994) The taxonomy and species of birds of Australia and its territories. Monograph 2. Royal Australasian Ornithologists Union, Hawthorn East, Victoria, 1–29.

Cox-Witton K, Reiss A, Woods R et al. (2014) Emerging Infectious Diseases in Free-Ranging Wildlife–Australian Zoo Based Wildlife Hospitals Contribute to National Surveillance. PLoS ONE 9(5): e95127. doi: 10.1371/journal.pone.0095127

CSIRO (2007) Climate Change in Australia. Technical Report 2007. CSIRO and Bureau of Meteorology.

Department of Environment and Conservation (2012) Carnaby's Cockatoo (*Calyptorhynchus latirostris*) Recovery Plan. Western Australian Wildlife Management Program No. 52. Department of Environment and Conservation, Perth, Western Australia, 1–56.

Doley A (1995) Networks needed by individual farmers: a personal perspective from the Northern Wheatbelt of Western Australia. In: Saunders DA, Craig JL, Mattiske EM (Eds) Nature Conservation 4: the Role of Networks. Surrey Beatty & Sons, Chipping Norton, New South Wales, 241–250.

Doley A (2003) "Koobabbie": ecological and economic sustainability. Pacific Conservation Biology 9: 42–48.

Environmental Protection Authority (2004) Environmental Protection (Clearing of Native Vegetation) Regulations 2004. Amendments published 4 December 2013. http://www.slp.wa.gov.au/legislation/statutes.nsf/main_mrtitle_1384_homepage.html [accessed 28 July 2014]

Garnett ST, Pedler LP, Crowley GM (1999) The breeding biology of the Glossy Black-Cockatoo *Calyptorhynchus lathami* on Kangaroo Island, South Australia. Emu 99: 262–279 doi: 10.1071/MU99032

Gibbons P, Lindenmayer D (2002) Tree hollows and wildlife conservation in Australia. CSIRO Publishing, Melbourne, Victoria, 1–211.

Goldingay RL (2009) Characteristics of tree hollows used by Australian birds and bats. Wildlife Research 36: 394–409. doi: 10.1071/WR08172

Goldingay RL (2011) Characteristics of tree hollows used by Australian aboreal and scansorial mammals. Australian Journal of Zoology 59: 277–294. doi: 10.1071/ZO11081

Griffiths R, Double MC, Orr K, Dawson RJG (1998) A DNA test to sex most birds. Molecular Ecology 7: 1071–1075. doi: 10.1046/j.1365-294x.1998.00389.x

Harris JBC, Fordham DA, Mooney PA et al. (2012) Managing the long-term persistence of a rare cockatoo under climate change. Journal of Applied Ecology 49: 785–794. doi: 10.1111/j.1365-2664.2012.02163.x

Hennessy K, Fawcett R, Kirono D et al. (2008) An Assessment of the Impact of Climate Change on the Nature and Frequency of Exceptional Climatic Events. Commonwealth of Australia, Barton, Australian Capital Territory. http://www.daff.gov.au/__data/assets/pdf_file/0007/721285/csiro-bom-reportfuture-droughts.pdf [accessed 4 July 2011]

IUCN (2014) The IUCN Red List of Threatened Species. Version 2014.2. http://www.iucnredlist.org [accessed 28 July 2014]

Jackson C (2009) Assessing and quantifying canola crop damage by Carnaby's Black-Cockatoo *Calyptorhynchus latirostris* in the south-west of Western Australia. M.Sc. thesis, University of Sydney, New South Wales.

Mawson PR, Long JL (1994) Size and age parameters of nest trees used by four species of parrot and one species of cockatoo in South-west Australia. Emu 94: 149–155. doi: 10.1071/MU9940149

McNeely JA, Gadgil M, Leveque C et al. (1995) Human influences on biodiversity. In: Heywood VH, Watson RT (Eds) Global Biodiversity Assessment. Cambridge University Press, Cambridge, 711–821.

Mooney PA, Pedler LP (2005) Recovery Plan for the South Australian subspecies of the Glossy Black-Cockatoo (*Calyptorhynchus lathami halmaturinus*): 2005-2010. Department of Environment South Australia.

Newton I (1994) The role of nest sites in limiting the numbers of hole-nesting birds: a review. Biological Conservation 70: 265–276. doi: 10.1016/0006-3207(94)90172-4

Rowley I (1990) Behavioural ecology of the galah *Eolophus roseicapillus* in the wheatbelt of Western Australia. Surrey Beatty & Sons in association with the Commonwealth Scientific and Industrial Organisation, Division of Wildlife and Ecology and the Royal Australasian Ornithologists Union, Chipping Norton, New South Wales, 1–188.

Saunders DA (1974) Subspeciation in the White-tailed Black Cockatoo, *Calyptorhynchus baudinii*, in Western Australia. Australian Wildlife Research 1: 55–69. doi: 10.1071/WR9740055

Saunders DA (1979) The biology of the short-billed form to the White-tailed Black Cockatoo, *Calyptorhynchus funereus latirostris* Carnaby. Ph. D. Thesis, University of Western Australia, Crawley, Western Australia.

Saunders DA (1980) Food and movements of the short-billed form of the White-tailed Black Cockatoo. Australian Wildlife Research 7: 257–269. doi: 10.1071/WR9800257

Saunders DA (1982) The breeding behaviour and biology of the short-billed form of the White-tailed Black Cockatoo *Calyptorhynchus funereus*. Ibis 124: 422–455. doi: 10.1111/j.1474-919X.1982.tb03790.x

Saunders DA (1986) Breeding season, nesting success and nestling growth in the Carnaby's cockatoo *Calyptorhynchus funereus latirostris* over 16 years at Coomallo Creek and a method for assessing the viability of populations in other areas. Australian Wildlife Research 13: 261–73. doi: 10.1071/WR9860261

Saunders DA (1990) Problems of survival in an extensively cultivated landscape: the case of Carnaby's Cockatoo *Calyptorhynchus funereus latirostris*. Biological Conservation 54: 111–124. doi: 10.1016/0006-3207(90)90057-V

Saunders DA (2006) Cats and cockatoo chicks. In: Olsen P, Silcocks A, Weston M (Eds) The State of Australia's Birds 2006: Invasive Species. Birds Australia, Hawthorn East, Victoria, 13.

Saunders DA, Doley A (2013) The birds of "Koobabbie" in the northern wheatbelt of Western Australia (1987–2011) and the contribution of the farm to conservation of the region's avifauna. Pacific Conservation Biology 19: 204–232.

Saunders DA, Hobbs RJ, Margules CR (1991) Biological consequences of ecosystem fragmentation: a review. Conservation Biology 5: 18–32. doi: 10.1111/j.1523-1739.1991.tb00384.x

Saunders DA, Ingram JA (1987) Factors affecting survival of breeding populations of Carnaby's Cockatoo *Calyptorhynchus funereus latirostris* in remnants of native vegetation. In: Saunders DA, Arnold GW, Burbidge AA, Hopkins AJM (Eds) Nature Conservation: the Role of Remnants of Native Vegetation. Surrey Beatty & Sons, Chipping Norton, New South Wales, 249–258.

Saunders DA, Ingram JA (1995) Birds of Southwestern Australia. An Atlas of Changes in Distribution and Abundance of the Wheatbelt Avifauna. Surrey Beatty & Sons, Chipping Norton, New South Wales, 1–296.

Saunders DA, Ingram JA (1998) Twenty-eight years of monitoring a breeding population of Carnaby's Cockatoo. Pacific Conservation Biology 4: 261–270.

Saunders DA, Dawson R, Mawson P (2011a) Photographic identification of banded Carnaby's Black Cockatoos. Corella 35: 52–54.

Saunders DA, Mawson P, Dawson R (2011b) The impact of two extreme weather events and other causes of death on Carnaby's Black Cockatoo: a promise of things to come for a threatened species? Pacific Conservation Biology 17: 141–148.

Saunders DA, Mawson PR, Dawson R (2014a) Use of tree hollows by Carnaby's Cockatoo and the fate of large hollow-bearing trees at Coomallo Creek, Western Australia 1969–2013. Biological Conservation 117: 185–193. doi: 10.1016/j.biocon.2014.07.002

Saunders DA, Mawson PR, Dawson R (2014b) One fledgling or two in Carnaby's Cockatoo (*Calyptorhynchus latirostris*) – a strategy for survival or legacy from a bygone era? Conservation Physiology 2. doi: 10.1093/conphys/cou001

Saunders DA, Smith GT, Ingram JA, Forrester RI (2003) Changes in a remnant of salmon gum *Eucalyptus salmonophloia* and York gum *E. loxophleba* woodland, 1978 to 1997.

Implications for woodland conservation in the wheat-sheep regions of Australia. Biological Conservation 110: 245–256. doi: 10.1016/S0006-3207(02)00223-9

Saunders DA, Rowley I, Smith GT (1985) The effects of clearing for agriculture in the distribution of cockatoos in the southwest of Western Australia. In: Keast A, Recher HF, Ford H, Saunders D (Eds) Birds of Eucalypt Forest and Woodlands: Ecology, Conservation, Management. Surrey Beatty & Sons, Chipping Norton, New South Wales, 309–321.

Saunders DA, Wintle BA, Mawson PR, Dawson R (2013) Egg-laying and rainfall synchrony in an endangered bird species; implications for conservation in a changing climate. Biological Conservation 161: 1–9. doi: 10.1016/j.biocon.2013.02.004

State of the Environment Advisory Council (1996) State of the Environment: Australia 1996. CSIRO Publishing, Collingwood, Victoria.

Steane DA, Potts BM, McLean E et al. (2014) Genome-wide scans detect adaptation to aridity in a widespread forest tree species. Molecular Ecology 23: 2500–2513. doi: 10.1111/mec.12751

White NE, Bunce M, Mawson PR et al. (2014) Identifying conservation units after large-scale landclearing: a spatio-temporal molecular survey of endangered white-tailed black-cockatoos (*Calyptorhynchus* spp.). Diversity and Distributions. doi: 10.1111/ddi.12202

White NE, Dawson R, Coghlan ML et al. (2012) Application of STR markers in wildlife forensic casework involving Australian black-cockatoos (*Calyptorhynchus* spp.). Forensic Science International: Genetics 6: 664–670. doi: 10.1016/j.fsigen.2011.10.003

White NE, Mawson PR, Dawson R et al. (2009) Characterisation and cross-species utility of 20 microsatellite markers for population and forensic applications in the endangered Carnaby's Black-cockatoo, *Calyptorhynchus latirostris*. Conservation Genetics Resources 1: 341–345. doi: 10.1007/s12686-009-9079-7